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TITLE: Examining the C1-P1 Pseudorange Bias

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BIOGRAPHIES

All three authors are currently Members of the Technical Staff at the Jet Propulsion Laboratory (JPL), California Institute of Technology. David Jefferson holds a B.S. degree in Aeronautics and Astronautics from the Massachusetts Institute of Technology. He works primarily as lead analyst for JPL's precise GPS processing contribution to the International GPS Service (IGS) combined products, and is a member of the Orbiter and Radio Metric Systems Group.

Michael Heflin earned a Ph.D. in physics from the Massachusetts Institute of Technology. As a member of JPL's Satellite Geodesy and Geodynamics Systems Group, he has been working on research and development related to the Global Positioning System for ten years. He is a co-patent holder for JPL's GIPSY software and has appeared on NBC Nightly News. Current research topics include software development, data analysis, improvements in the global reference frame, and interpretation of crustal deformation measurements.

Ronald Muellerschoen received a B.S. degree in physics at Rensselaer Polytechnic Institute and a M.S. degree in applied math at the University of Southern California. He is also a Member of the Technical Staff in JPL's Orbiter and Radio Metric Systems Group. His work at JPL has concentrated on the development of filtering software for processing GPS data and development of wide area differential systems.

ABSTRACT

Use of GPS tracking data from different dual-frequency receiver types (cross-correlating vs. codeless) has revealed satellite-dependent biases in pseudorange observables P1 (Y-code) and C1 (C/A, Clear Acquisition code). These biases can have a direct effect on clock estimates,

carrier phase bias fixing, and other parameters estimated in GPS data processing. A set of satellite-specific compensatory pseudorange offsets is calculated, and each is applied to a week of daily global network analyses in which satellite, receiver, atmospheric, and Earth rotation parameters are estimated. Results from these analyses are then compared to those from corresponding baseline cases in which no biases were applied. There is also some evidence that suggests that the pseudorange biases differ even among codeless receiver models. Hence, a second set of offsets is computed on a different basis, and compared with the baseline model in a similar manner. A preliminary examination of C1-P1 variations over time is presented. Finally, recommendations are made for the use of the calculated offsets, and consideration is given to future dissemination of updates to these values as necessary.

INTRODUCTION

Since June 1992, the International GPS Service (IGS) has maintained a network of geodetic-grade GPS receivers at various locations throughout the world (Beutler, 1993; Neilan & Noll, 1993). The civilian, scientific, and military communities use data from these receivers for precise navigation, geodetic positioning, geophysical and atmospheric research, and time transfer. Over time, the global network of ground stations has not only grown in number, but also changed in equipment composition. Whereas originally the network was made up of essentially one type of receiver, regular maintenance and the desire to modernize and make use of higher quality, later-model receivers have brought about its current employment of a mixture of receiver types.

Typically, raw binary tracking data is offloaded from the various receivers and converted to standard RINEX (Receiver INdependent EXchange) format for post-processing. It is the use

of this variety of data that has brought about the discovery of biases between the observables from different GPS receivers. In particular, the data supplied from stations in the network employing Rogue, TurboRogue, and Trimble receivers contain C1 (C/A) pseudorange and L1 carrier phase based on C1. In contrast, RINEX data from sites using codeless receivers like Ashtech Z-XII, Benchmark, and ACT-upgraded TurboRogues contain directly-measured P1 pseudorange and L1 carrier phase based on P1 (Ray, Dragert, & Kouba, 1999). The biases between the two pseudorange observables P1 and C1 are satellite-dependent, and can have an impact on estimated GPS clock solutions and carrier phase ambiguity resolution. There is a necessity to correct for these biases so that measurements from an ensemble of receivers may be internally consistent, yielding more accurate final results.

METHOD

Calculation of C1-P1 Biases

Pseudorange biases have been computed at JPL at different times since 1997 (Muellerschoen & Powers, 1999). C1 and P1 range data were collected every second from a real-time stream of measurements from a network of 14 Ashtech Z-XII receivers, then differenced to form C1-P1 for all satellites, over all stations in the network. Then every hour the mean and scatter of the C1-P1 data were computed for all satellites and stations, and the scatter was used as a data weight. Using a least-squares filter, we estimated C1-P1 for each individual satellite and station. This is equivalent to double differencing and is a floating solution, since a reference satellite or station was not specified. We then selected a station as a reference (TIDB, located at Tidbinbilla, Australia) and adjusted all estimates for that hour, so that the reference station had the same value at all hourly solutions. The biases were then normalized so that they

had zero mean; in this way the receiver clock bias remained unchanged. As an extension of the investigation, a second set of biases was calculated in the same manner, but based on a network of 4 AOA Benchmark receivers. In this case, the ground site SANT (located at Santiago, Chile) was used as reference station. Values used from the separate Ashtech and Benchmark calculations are shown in Table 1. The two sets of values differ by 98 mm (0.3 ns), RMS, which is consistent with Ashtech/Benchmark comparison results obtained by Gao, et al., 1999.

Application of C1-P1 Biases

Ninja is the module of the JPL-developed GIPSY/OASIS-II GPS processing software package which performs tracking observation data editing, cycle slip detection, and decimation on individual RINEX files (Webb & Zumberge, 1997). The utility *qfront* is used to run *ninja* on multiple stations and merge the individual edited files. The output of these modules is a binary file in JPL's "quick measurement" format (often known as a "*qmfile*"), and typically contains the ionosphere-free combinations of the observables (PC and LC) from each station-satellite pair as a function of time. A record of the receiver types used in each solution is kept by *qfront*. A utility named *p2ca* then operates on the *qmfile* by adding (or subtracting) the previously-determined values of C1-P1 biases to (or from) data from the appropriate ground sites, depending on whether it is desired to convert C/A code to P1, or vice-versa. In our tests, we opted to convert the C/A code found in the TurboRogue and Trimble receivers to P1, since the IGS network is moving toward a codeless receiver ground network.

Comparison of C1-P1 Bias Results

After applying the appropriate bias values to the pseudorange data, global network processing is allowed to continue normally using GIPSY through the remainder of the FLINN analysis process used by the JPL IGS Analysis Center for regular weekly orbit, clock, and station coordinate contributions to the IGS precise products (Jefferson, Bar-Sever, Heflin, Webb, & Zumberge, 2000). This was repeated for each day for data spanning the period February 27 through March 4, 2000 (GPS week 1051). The daily results from each of the Ashtech- and Benchmark-based tests were then contrasted with corresponding nominal FLINN results, which contained no C1-P1 adjustments to the data. These comparisons are discussed in the next section.

RESULTS

First, it may be of interest to know what the makeup of the ground network was for our tests. As with all of our current analyses, we selected 42 well-distributed stations from over 240 that are in the IGS global network. A breakdown of the stations with respect to receiver type is shown in Table 2. On average, 43% of the sites used were of the cross-correlating (C1) type to which bias corrections were applied, and 57% were of the codeless (P1) type and had no corrections.

All three cases (FLINN, Ashtech, and Benchmark) had similar outcomes with respect to number of data point outliers (about 500 of 160,000 points per day); goodness-of-fit (approximate χ^2 of 0.4 per day); and post-fit residuals (about 53 cm for pseudorange, and 5 mm for phase). Differences between the cases were manifested in orbit, clock, and station coordinate products, as well as in phase ambiguity resolution. One measure of orbit quality used was

consistency; that is, how well each day's orbit solution compared with those from adjacent days. As we have typically done for our orbit contributed to the IGS combination, we differenced 3 hours at the beginning and end of each day with overlapping solutions from the previous and following days, and repeated this for each case. The 3-D median of these results for the entire week is shown in Figure 1; Benchmark-based results had the best repeatability at 7.4 cm. Another orbit performance check we did was to compare each day's solution to the corresponding FLINN and IGS orbits, the latter serving as a second baseline model. (It is noted that since FLINN solutions are used in creating the IGS combination orbit, the IGS comparisons are not completely independent.) The summary of these orbit comparisons for the full week is shown in Figure 2.

As mentioned earlier, the C1-P1 adjustments are expected to effect changes in the GPS satellite clock solutions once the pseudorange data are modified. As shown in Figures 3 and 4, the signature of the input C1-P1 values is tracked very consistently by the corresponding mean difference in clock estimates (w.r.t. FLINN) for each satellite. The magnitudes of the output clocks are not as large as their corresponding bias inputs, as less than half of the receivers had any modifications made to their data. Additionally, Figure 5 shows the difference in the actual clock solutions over the entire week for a typically behaving satellite, PRN25. The RMS change for the Ashtech and Benchmark results for this satellite are 75 and 100 mm respectively.

We also expect the input pseudorange biases to have an effect on global phase ambiguity resolution. This is displayed in Figure 6, and it is clear that making the bias adjustments has a favorable impact in this realm, in that 141 and 174 more phase ambiguities are resolved on average in the Ashtech and Benchmark tests, respectively.

Finally, we examined the differences in ground station coordinates realized from introducing C1-P1 bias values. In Figure 7, it is shown that the use of the biases does change the computed positions of the ground stations, with the most pronounced effect appearing in the vertical component in both the Ashtech and Benchmark test cases. Station position changes both prior and subsequent to phase ambiguity resolution are displayed.

CONCLUSIONS

It has been shown that biases between the pseudorange observables P1 and C1 do exist when analyzing data from a network of mixed receiver types. These biases can range from a few to hundreds of millimeters, depending on the GPS satellite involved. The differences in pseudorange values can be estimated, and when applied to the appropriate receivers, do noticeably modify analysis results. Quantitatively, changes observed were a decrease of 1-2 cm in satellite orbit repeatability; a range of 20-200 mm (0.07-0.67 ns) RMS difference in clocks over all satellites; an increase on the order of 160 more carrier phase ambiguities resolved, and a 2-4 mm change in station coordinates. Based on orbit repeatability and bias fixing results, we regard these changes as improvements in the final solutions.

It does seem, however, that receivers reporting P1 even behave differently amongst themselves, and that it may matter which set of biases are used. Benchmark-based results generally had larger differences with our nominal cases than those based on Ashtech calculations. The real reason for this is not yet understood and may depend on the composition of the 42-site network that was used, different internal receiver processing algorithms, or the strategy used to estimate the C1-P1 biases.

Temporal variations of the C1-P1 biases were also examined using Ashtech biases calculated on 8 sporadic occasions between December 1997 and August 2000. The standard deviation was computed to be about 18 mm per satellite per year. In contrast, each day's set of bias values had a scatter amongst the satellites of about 288 mm. Because the variation in time is an order of magnitude smaller than the scatter in the individual sets of values, we are considering the C1-P1 values as relatively constant. These may only need updating as new GPS satellites are launched.

At this time, our recommendation is for the use of the most recent Benchmark-based C1-P1 corrections shown in the third column of Table 1, which were calculated on August 31, 2000. The JPL IGS Analysis Center expects to switch from the currently used Ashtech values (column 2) as soon as is feasible. We also expect to publish (via internet) new suggested values of these biases when new satellites become available, and will continue to monitor their change over time. It is recognized that once the IGS network is entirely made up of P1-reporting receivers, the need for applying the biases described here will no longer be necessary for the analysis of this particular set of stations. Until then, the smaller biases between different P1-reporting receivers may require continued attention to produce the most accurate results.

ACKNOWLEDGMENT

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FIGURE CAPTIONS

Figure 1: Orbit overlaps from each test case. “CA2PA” refers to Ashtech tests; “CA2PB” refers to Benchmark tests.

Figure 2: Week-long summary of C1-P1 tests with FLINN (black) and IGS (gray) orbits. “CA2PA” refers to Ashtech tests; “CA2PB” refers to Benchmark tests.

Figure 3: Ashtech-based clock differences with input bias values.

Figure 4: Benchmark-based clock differences with input bias values.

Figure 5: Clock differences with FLINN for PRN25 for both test cases.

Figure 6: Improvement of phase ambiguity resolution when C1-P1 biases are applied.

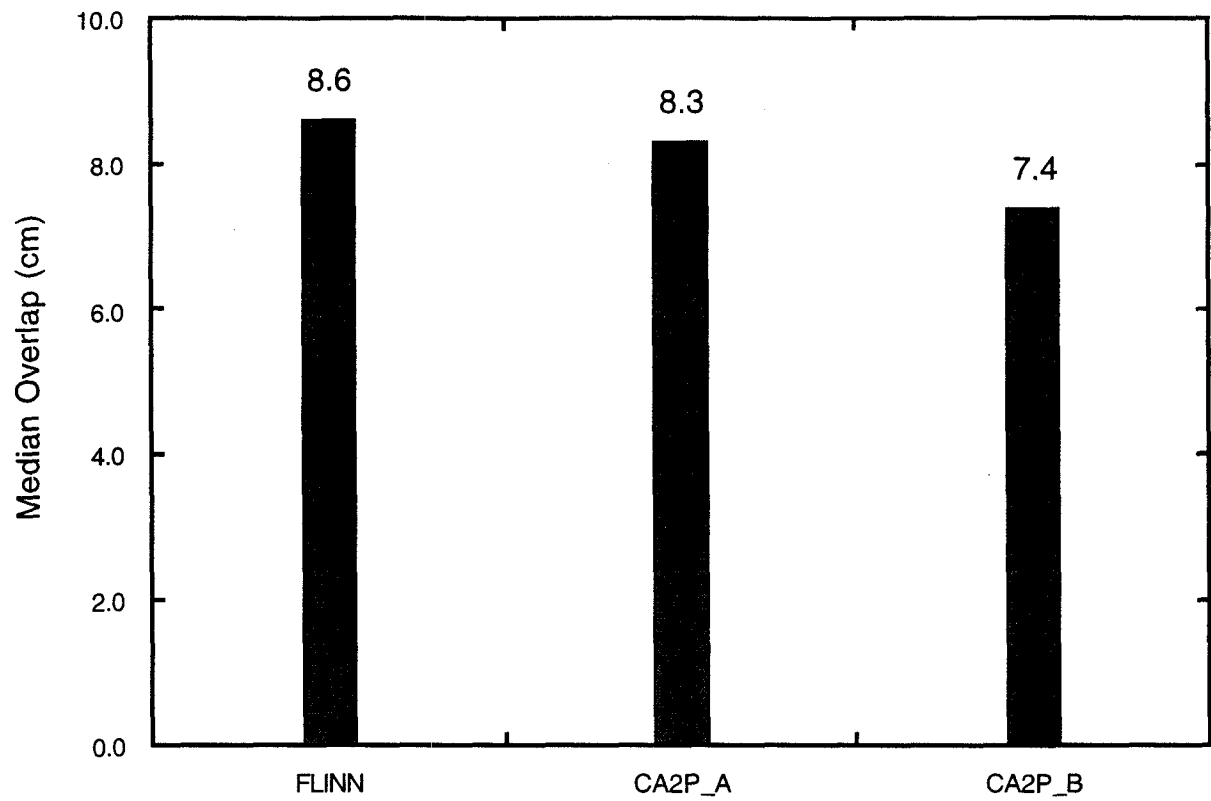
Figure 7: Station coordinate comparisons with the nominal FLINN case. Results are shown for coordinate solutions obtained before and after global ambiguity resolution is done.

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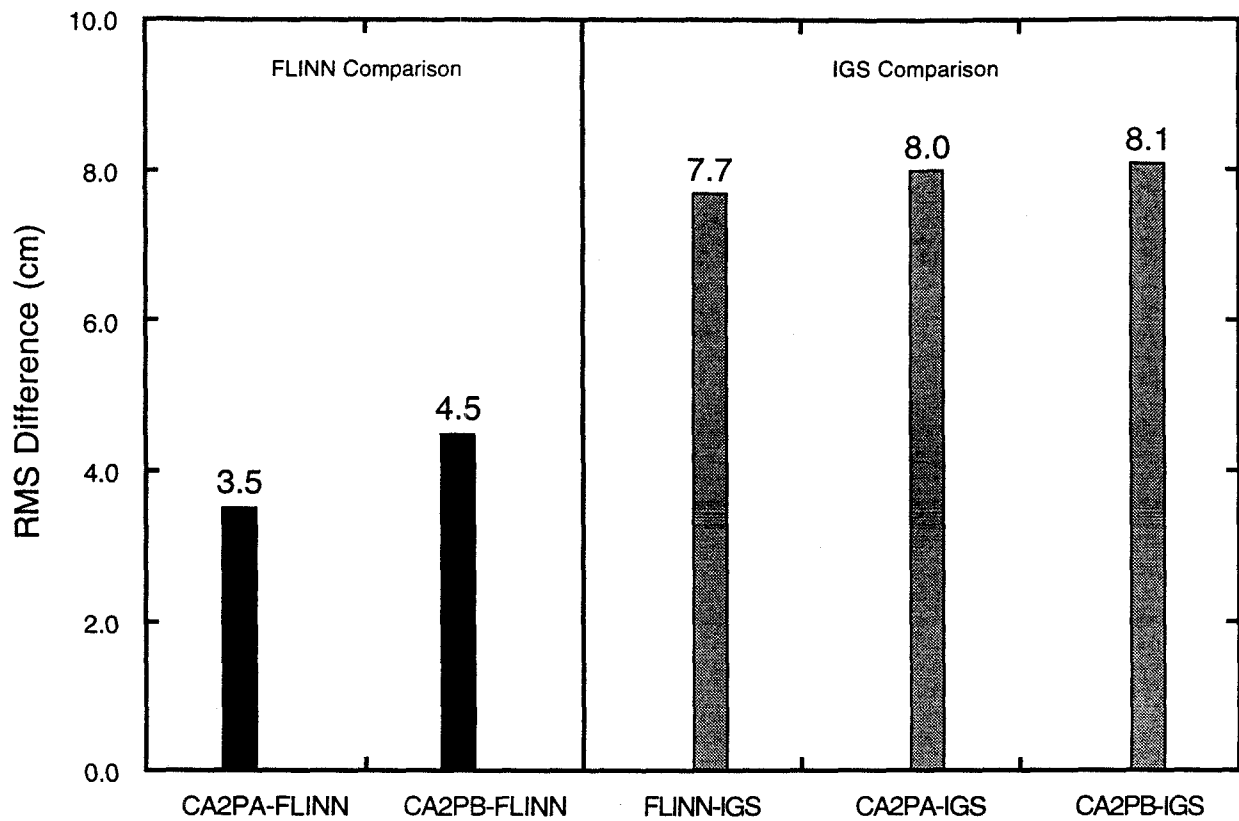
Table 1: Calculated Ashtech- and Benchmark-based P1-C1 biases. Unavailable satellites are indicated by “—”. The RMS difference between the two sets of values is 98 mm.

Table 2: Receiver types used during GPS week 1051 test. 42 total stations were used each day. (¹One TurboRogue, NICO, was ACT-upgraded during the test and erroneously received Benchmark bias corrections on March 3. ²One TurboRogue, MAW1, was ACT-upgraded and erroneously received Ashtech bias corrections on March 4.)

C1-P1 Test - GPS Orbit Overlaps GPS Week 1051

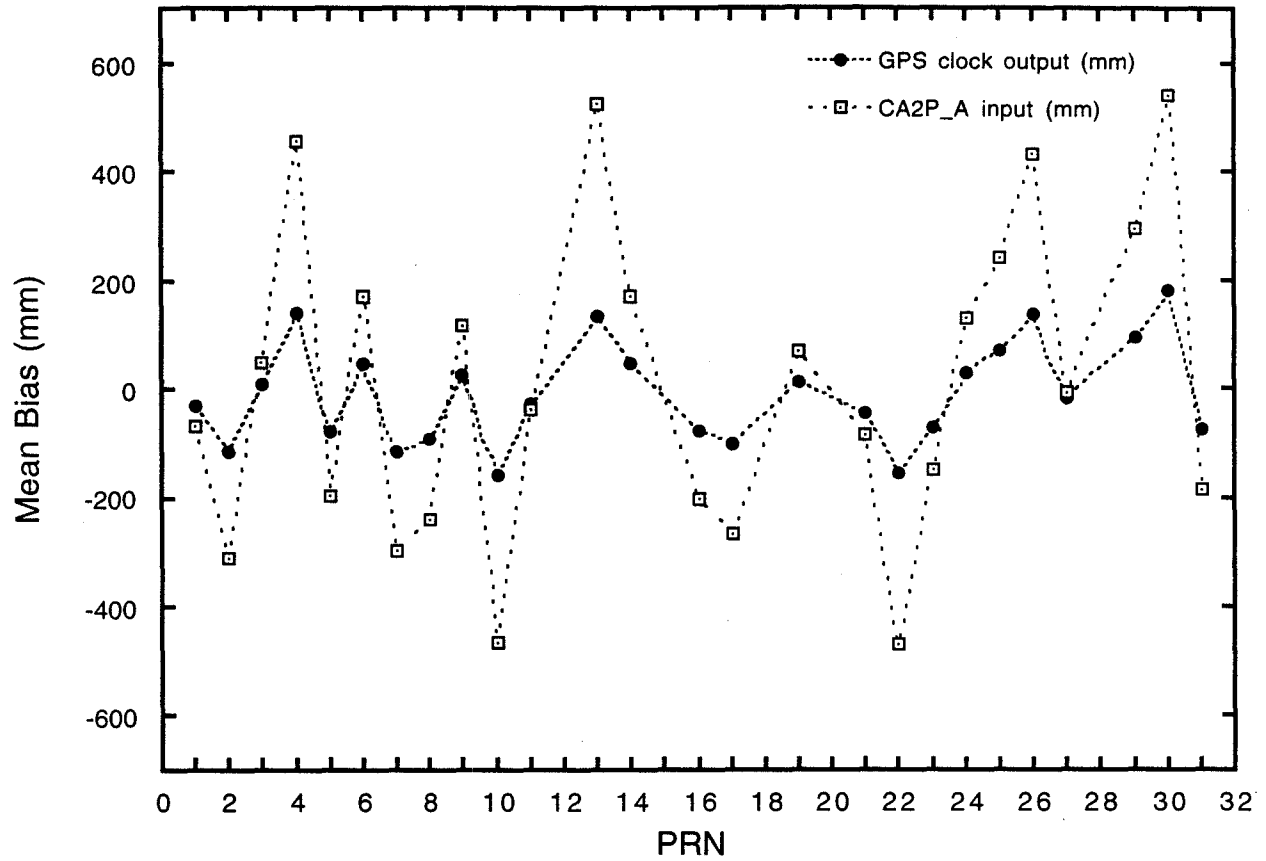


C1-P1 TEST: 3D Orbit Difference Week 1051



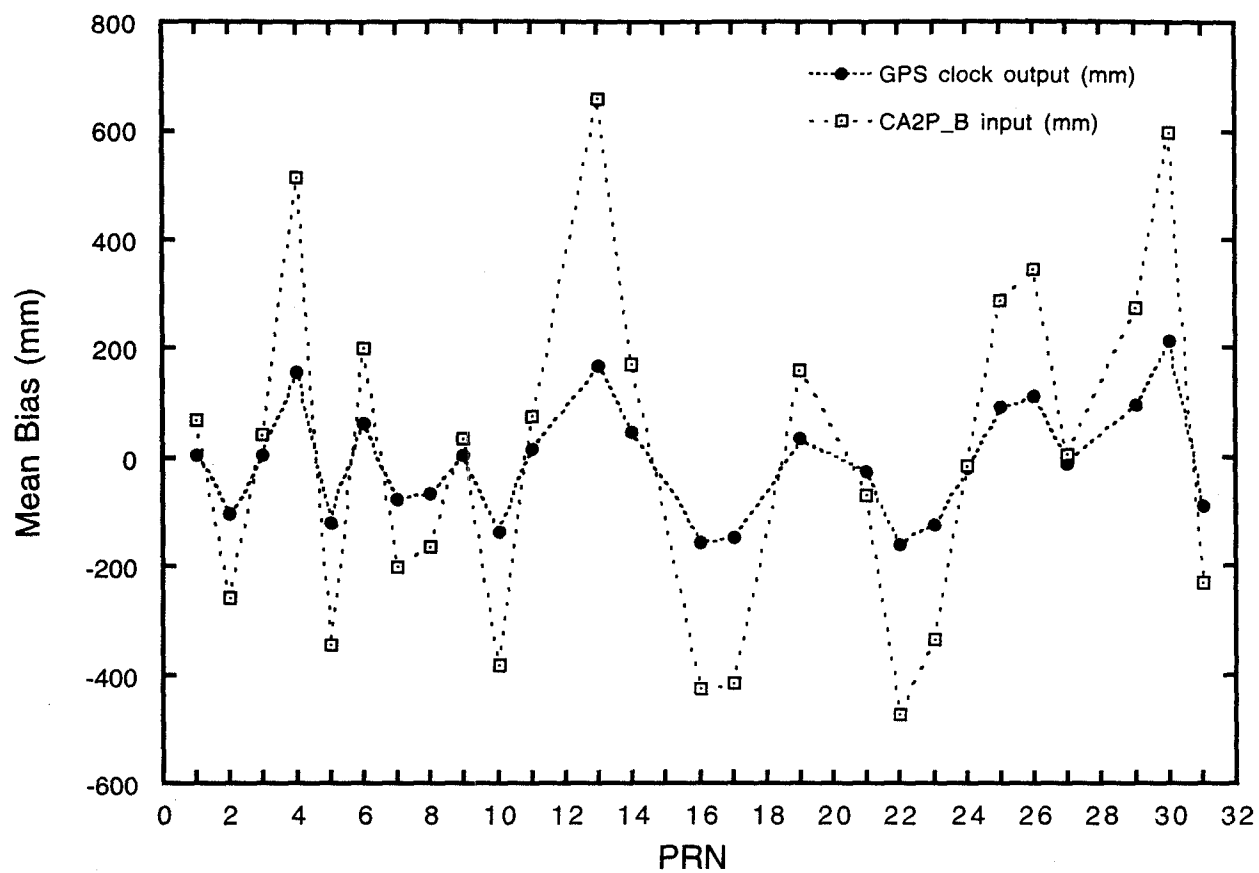
C1-P1 Test: GPS Clocks, Week 1051

(Ashtech-based, RMS difference = 191 mm = 0.6 ns)

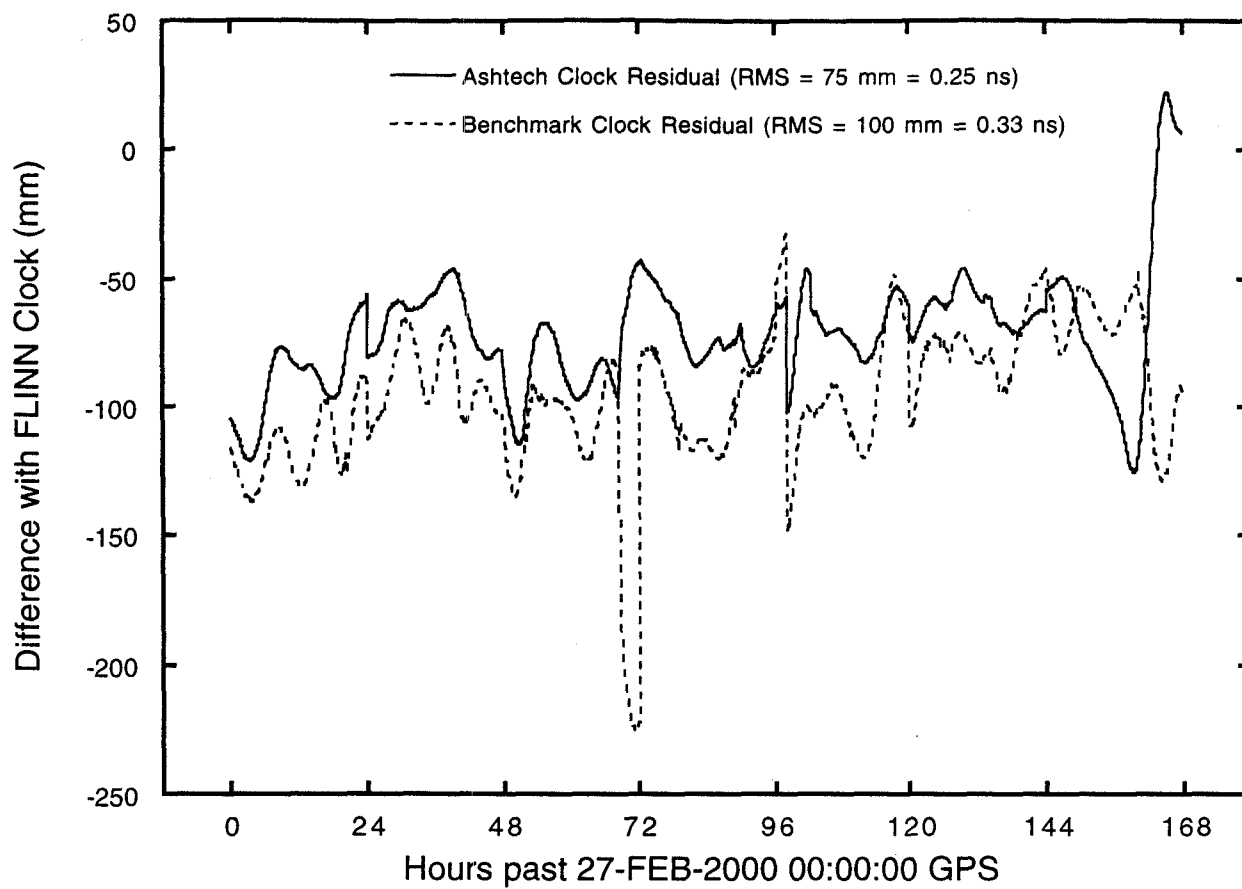


C1-P1 Test: GPS Clocks, Week 1051

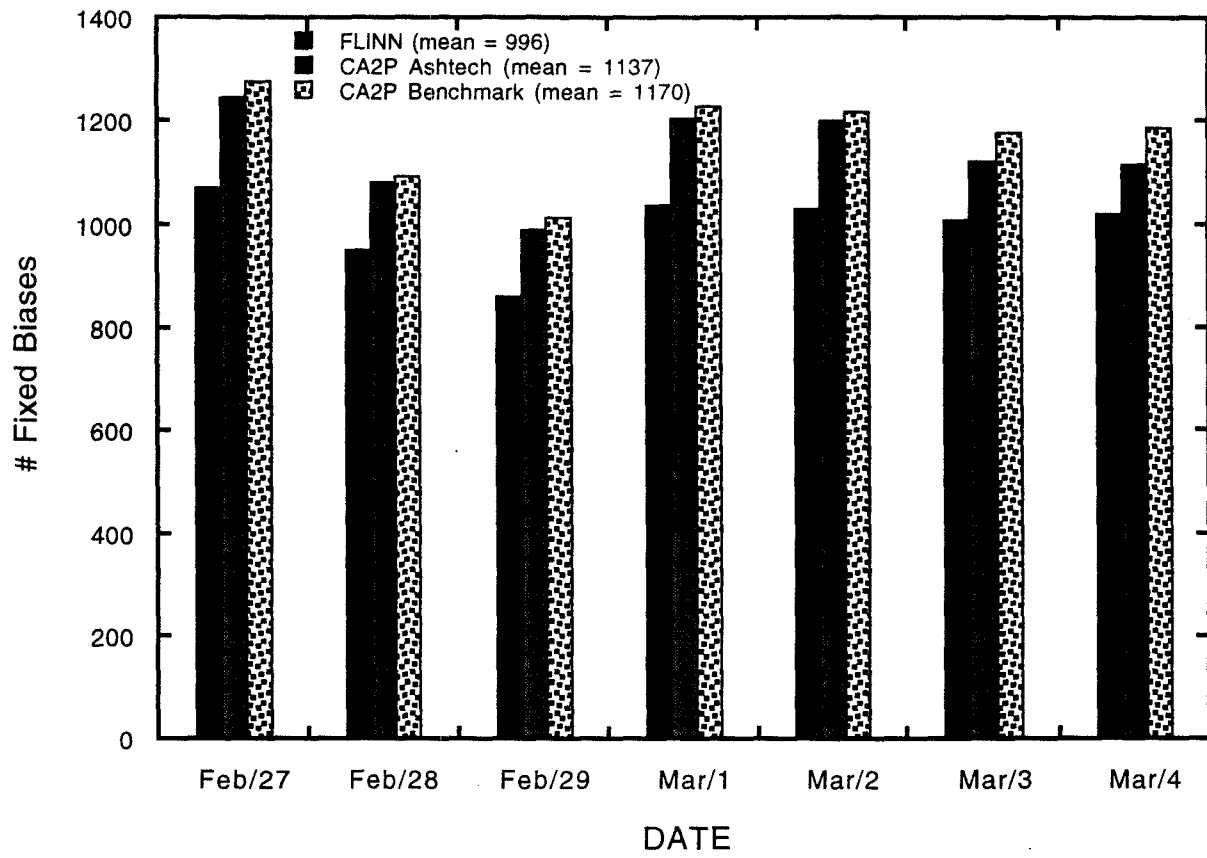
(Benchmark-based, RMS difference = 212 mm = 0.7 ns)



C1-P1 Test: GPS Clocks, Week 1051, PRN25



C1-P1 TEST: Ambiguity Resolution, Week 1051



C1-P1 TEST: Station Coordinates, Week 1051

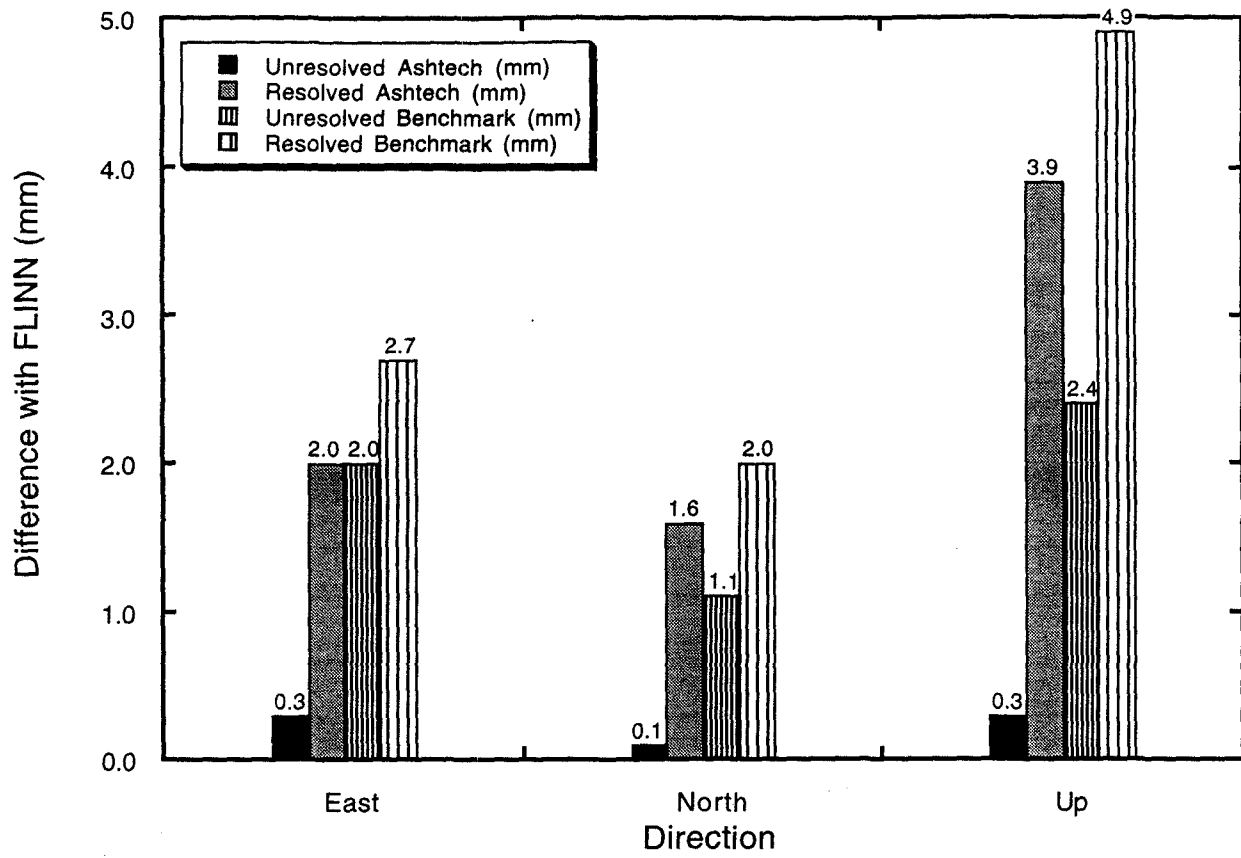


Table 1: Calculated Ashtech- and Benchmark-based P1-C1 biases. Unavailable satellites are indicated by “—”. The RMS difference between the two sets of values is 98 mm.

PRN	Ashtech (mm)	Benchmark (mm)	Difference (mm)
1	-67	70	137
2	-308	-255	53
3	52	43	-9
4	458	515	57
5	-195	-344	-149
6	172	201	29
7	-296	-200	96
8	-240	-161	79
9	117	36	-81
10	-465	-382	83
11	-35	78	113
12	--	--	--
13	526	658	132
14	172	172	0
15	-297	-230	67
16	-202	-425	-223
17	-266	-415	-149
18	52	133	81
19	70	160	90
20	--	-163	--
21	-84	-67	17
22	-469	-471	-2
23	-147	-333	-186
24	132	-15	-147
25	242	290	48
26	433	345	-88
27	-7	6	13
28	--	-7	--
29	296	274	-22
30	541	598	57
31	-183	-230	-47

Table 2: Receiver types used during GPS week 1051 test. 42 total stations were used each day. (¹One TurboRogue, NICO, was ACT-upgraded during the test and erroneously received Benchmark bias corrections on March 3. ²One TurboRogue, MAW1, was ACT-upgraded and erroneously received Ashtech bias corrections on March 4.)

	Feb 27	Feb 28	Feb 29	Mar 1	Mar 2	Mar 3 ¹	Mar 4 ²
C1-type:	20	19	19	17	17	18	15
TurboRogue	16	14	17	15	16	17	15
Trimble	4	5	2	2	1	1	1
P1-type:	22	23	23	25	25	24	27
ACT/Benchmark	16	16	15	17	16	16	21
Ashtech	6	7	8	8	9	8	6